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Effect on Lettuce Growth Depending on LED Light Distance

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Abstract: Due to a constantly increasing world population, a decrease of farm land, climate changes and food safety concerns, many companies have gotten involved in plant factories that grow certain crops regardless of the weather of environment. In the plant factory, the growing environment can be controlled and the crop can also be controlled. As one of control factors, this study studies the effects on lettuce growth which varies considerably by LED light intensity along the distance. For showing the effects, lettuce production in the plant factory is compared and analyzed.

Key words: Plant factory, lettuce, LED, distance, environment, Korea

INTRODUCTION

Because of climate change, producing crops steadily is a difficult thing to do. There are many safety concerns for food because of environmental issues and chemicals such as pesticides. A growing number of people are questioning about what they are putting in their bodies: how it was raised who raised it and how it was delivered to grocery stores. More consumers want to know if they are eating the safe foods (Kallen, 2004). Due to these concerns, indoor growing systems became popular and many companies have started to look into the home and commercial size systems (Kallen, 2004; Davis, 2006; Takatsuji, 2007, 2010; Oyabu and Katube, 2009; Shibata *et al*., 2010; Lee, 2010a, b; Kim, 2009; Son, 1997; Baluska *et al*., 2006).

Recently, plant factory has been establishing and takes off in worldwide countries. In the plant factory, the products are growing in an enclosed environment, therefore agricultural chemicals have no use. Secure and safe food producing system can be constructed. It is an effective way to control the growing environmental factors using physiology information which are directly obtained from the vegetable. Light plays a key role in plant growth (Shibata *et al*., 2010).

This study is intended to provide data to facilitate the plant factory in the economic aspects. Especially, cultivation under Light Emitting Diode (LED) light source is analyzed for finding the efficient method to show how much change in harvest depending upon LED light source combination. And the test subject is Lollo Rossa which is a classic Italian lettuce. According to the combination of LED light source and its illumination, growth historical data are collected and arranged with the information from the sowing to the harvest. Finally, based on the data, the results are discussed.

MATERIALS AND METHODS

LED bar for the plant factory: The experiment is accomplished by using hydroponic cultivation which applies to lettuce production. The prepared nutrient solution is used to supply nourishments. In addition, to make the growth condition optimal, the lettuce growth condition is investigated prior to the experiment. Based on the obtained information, the test is conducted in a suitable environment for the growth of lettuce. In an enclosed room, air heater/conditioner is installed and maintains the temperature 22°C. Environmental conditions are the same except LED position for the purpose of figuring out the growth change along the distance between lettuce and the LED light in Fig. 1.

In general, chlorophyll mostly absorbs light in a wavelength band of 430, 453, 642 and 662 nm, although, the absorption level varies according to the plant kind. This study uses a blue light of 400-470 nm and a red light of 630-700 nm and proper combination is required for plant lighting. The blue light is mainly to strengthen the stem and makes the leaves lush and the red light serves to promote the plant growth.

The configuration of the LED bar is red:white:blue = 4:2:1 and the reason for including a white light is wider distribution of the blue wavelength band, providing the necessary wavelength to plant growth and making the LED light similar to the natural light.

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Fig. 1: Growth cabinet

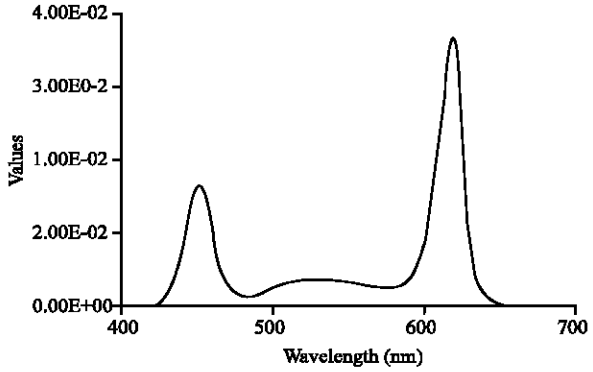

Fig. 2: Spectrum of the LED bar

Table 1: Control group

Variables	'A' Growth cabinet	'B'Growth cabinet	'C' Growth cabinet
LED install length	10 (cm)	20 (cm)	30 (cm)
Room temperature	22°C	22°C	22°C
Red:white:blue	4:2:1	4:2:1	4:2:1
Power consumption (W)	8.085 (W)	8.085 (W)	8.085 (W)
Culture medium	Use the same culture medium (EC: 0.85)		

The specification of LED bar in the experiment is 1 W and used a Model 5050 of wave-in, Korea. For the designed LED bar the spectrophotometry is applied to show the properness in plant growth. As a result, blue light of 450 nm and red light of 660 nm are peak points and 550 nm is also measured in Fig. 2. This establishes a ratio of suitable color composition to plant growth.

Illumination: In installing LED bar this study figures out the optimal condition to deliver the light most effectively according to the distance between the plant and the light. Three control groups are considered as shown in Table 1.

To find out how the distance A~C affects the photosynthetic activity of the lettuce Rollo Rossa, the test bed configuration is made as in Fig. 3.

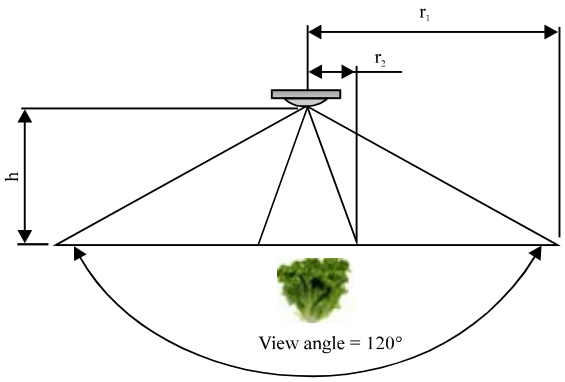

Fig. 3: Test bed configuration

In Fig. 3, h is the distance between lettuce leaves and the mounting position of the LED bar and the test distances are 10, 20 and 30 cm. As lettuce growing, the distance is reduced. So, to keep the distance, the LED bar position is adjusted. View angle of the LED bar is 120° and r_1 is the radius of the projected area of the LED when the distance is $h \times r_2$ is the radius of the light receiving area of lettuce and the value is actually 5 cm. By measuring the light intensity ratio according to the change of h, the amount of light which affects lettuce growth is calculated.

Illumination refers to the brightness of the surface when the light illuminates any surface. The symbol is written as E and the unit is lux or lx. Equation 1 for the intensity of the illumination is as follows:

$$E = \frac{F}{A} \quad (1)$$

where, F is the luminous flux incident on the area A. The assumption is used that there is no light loss during illuminating. A(h) = light illuminating area at the height h A = light receiving area of lettuce. The ratio of A(h) and A can be used as an estimate of the difference in efficiency of the three types of illumination and light receiving area of lettuce A is always the same, regardless of the height. Since, the value of A does not change, only A(h) is considered for the ratio and the Eq. 2 is:

$$A(h) = 2\pi r_1^2 = 2\pi(h \times \tan 60°)^2 \quad (2)$$

For three control groups, the computed results are as follows:

$$h = 10 \text{ cm} \Rightarrow A_1(10) = 2\pi \times (10 \times \tan 60°)^2 = 2\pi \times 17.3^2 = 589\pi \text{ cm}^2$$

$$h = 20\ cm \Rightarrow A_2(20) = 2\pi \times (20 \times \tan 60°)^2 = 2\pi \times 34.6^2 = 2.394\pi\ cm^2$$

$$h = 30\ cm \Rightarrow A_2(23) = 2\pi \times (30 \times \tan 60°)^2 = 2\pi \times 52^2 = 5.408\pi\ cm^2$$

The ratio is:

$$A_1 : A_2 : A_3 \approx 1 : 4 : 9 \quad (3)$$

and the ratio of the illumination intensity which is inverse proportional to the area A(h) is as follows:

$$E_1(10) : E_2(20) : E_3(30) = 9 : 4 : 1 \quad (4)$$

As a result, it can be expected that the height h = 10 cm is 9 times better than h = 30 cm in efficiency. For verification, this study analyzes the optical properties of the LED lighting.

In general, to measure the amount of light to be used for growing plants, the light intensity is considered. But this is the value to show the light intensity in the optesthesia, so, PPFD (Photosynthetic Photon Flux Density) should be considered in order to analyze the lighting effects on the plant growth. Plant uses accepted photons in light for photosynthesis and PPFD is a measure of the density of these photons. So, PPFD is more preferable to show the quantity of light necessary for the plant photosynthesis.

RESULTS AND DISCUSSION

PPFD is measured in the dark room and the measured points are P1-P3 of the LED bar as shown in Fig. 4 and the test is accomplished for each control group A~C.

PPFD TEST Environment:

- Place: Darkroom 1.5×2.0 m
- Condition: bottom-LED bar, measure mol at the height 10, 20, 30 cm
- Test point: P1-P3
- Test: Two times
- Voltage: 24 V

The average PPFD of the P_1~P_3 are 63.68, 26.55 and 15.99 μmol and the ratio is 4:1.6:1. The difference between the theoretical value and practical value comes from the light lost during illumination and the LED linearity error. PPFD of group A (63.68) is more than four times of group C value (15.99) and PPFD of group C is lower than the light compensation point 18 μmol. The light compensation point is the light intensity at which photosynthesis and respiration rate is the same and at least a light intensity which is more than the light compensation point, is required to grow plant. Group C shows a lower growth rate than other groups because the light is provided lower than the light compensation point which is expected to be difficult in normal growth.

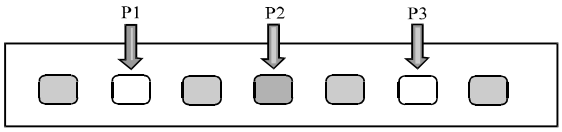

Fig. 4: Measurement points

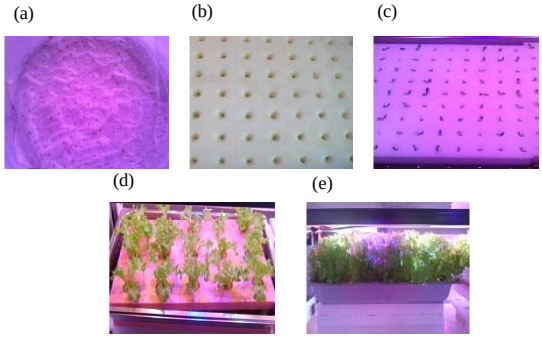

Fig. 5: Lettuce growth process: a) Wet sponge before planting seeds; b) Before germination; c) Cotyledons; d) After seeding (after 1 day) and e) After seeding (after 30 days)

Since, the actual installation of the LED bar, the data are collected with the cultivation of lettuce. The seeds of Rollo Rossa are germinated under the same conditions for the experiment and cultivated until growing into seedlings. Seeds are planted in a wet sponge with holes after soaking in water during a couple of hours as in Fig. 5a. After 4 or 5 days, cotyledons are formed as in Fig. 5c and when leaves are grown to 4 cm, seedlings are transferred to the plate. The 15 seedlings are in one plate and three plates are made for illumination test. The test is conducted for 36 days from the start and the temperature and length of leaves are daily measured and determined in the average as shown in Fig. 6 and 7.

Figure 6 is a graph showing the temperature change in the test chamber during experiment and the temperature is kept at 21-23°C on average. For the length of the leaves in Fig. 7, group A grows better than others and the area of the group B and C leaves is less than the area of group A leaves. In particular, Rollo Rossa of group C is not dense leafy and lacks of elasticity in Fig. 8, so, mouth feel is not even good. After 36 days, all the lettuce weights are measured including roots and the average is computed. Total 15 seedlings harvested from one plate are measured

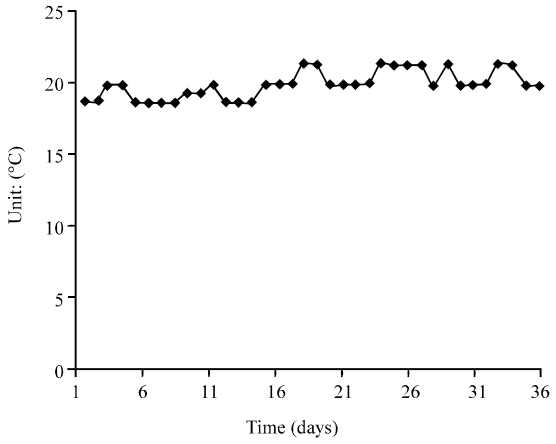

Fig. 6: Temperature changes

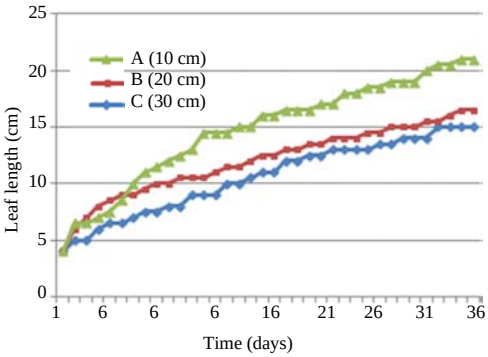

Fig. 7: Leaf length changes

Table 2: Lettuce weights

Number of measurements	A (10 cm)	B (10 cm)	C (10 cm)
1st	53 g	41 g	23 g
2nd	64 g	39 g	54 g
3rd	64 g	51 g	48 g
4th	31 g	50 g	39 g
5th	24 g	45 g	28 g
6th	22 g	40 g	38 g
7th	39 g	47 g	45 g
8th	56 g	34 g	55 g
9th	50 g	47 g	45 g
10th	41 g	27 g	46 g
11th	68 g	45 g	36 g
12th	48 g	30 g	29 g
13th	32 g	29 g	37 g
14th	69 g	49 g	17 g
15th	57 g	25 g	25 g
Total weight (including the roots)	718 g	599 g	565 g
Total weight (not including the roots)	423 g	345 g	283 g

and the weights are in Table 2. The total weight of the lettuce is measured twice including the roots and excluding the roots. This weight also shows that the group A grows much better than others.

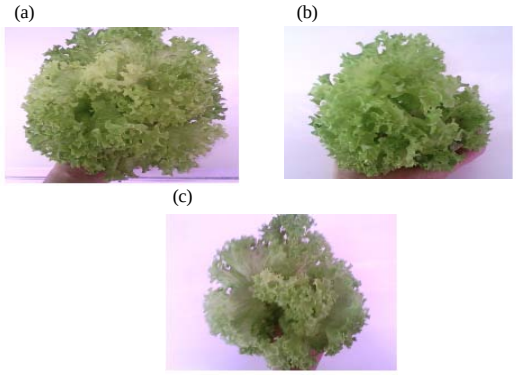

Fig. 8: Lettuce leaves: a) Group A; b) Group B and c) Group C

CONCLUSION

In this study, the optical properties of LED bar are analyzed through PPFD measurement. Control group A-C of lettuce and illumination in the growth cabinet are tested in accordance with the distance between plants and LED lighting. To show the validity of the experiment, Rollo rossa is used as a test subject and the growth is measured and PPFD is used for the light intensity. As a result of PPFD measurement, group A shows 63.68 μmol which is the highest value and group B is 26.55 μmol, group C is 15.99 μmol. So, PPFD of group C is less than the light compensation point 18 μmol which is not good to plant growth and the lettuce in group C shows the same results. By observation of Rollo Rossa, group A shows leafy and the weight is the most excellent and group C shows slow growth. This suggests that the plant do not grow normal due to the light deficiency caused by the distance which is longer than light compensation point. For the plant factory efficiency, the light with a wavelength 400-470 and 630-700 nm should be provided and also more light intensity than light compensation point is required. Even for the same lighting, minimizing the distance between the plant and the light gives much better result in efficiency from this experiment. When using the LED lights, the system is always necessary to keep a minimum distance between the plant and the light by making the height adjustable. This variable-height light system is expected to be able to obtain much better efficiency than the stationary light system.

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